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Ecosystem Carbon Storage and Partitioning in Chato Afromontane Forest: Its Climate Change Mitigation and Economic Potential

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***Abstract*— *Forests trap carbon dioxide (CO_2) from the atmosphere, store in the form of carbon (C) and regulate climate change. In this study, C storage and climate change mitigation potential of Chato Afromontane forest was assessed from measurement of the major pools including the aboveground biomass, belowground biomass, dead tree biomass, plant litter and soil organic carbon (SOC). The result showed that biomass accumulation was comparatively larger for natural forest than plantations due to maturity, intactness and species diversity. The total C storage capacity of the forest ranged from 107.12 Mg ha^{-1} for acacia plantation to 453.21 Mg ha^{-1} for the intact natural forest. The mean C storage capacity by major pools ranged from 1.36 Mg ha^{-1} for the dead tree C to 157.95 Mg ha^{-1} for the aboveground C pool. The forest ecosystem accumulated a total of nearly 6371.30 Gg C in the vegetation plus soil to a depth of 60 cm. Conservation of the sacred forest will have an imperative implication to net positive C addition and regulation of climate change.*

***Keywords*— *Chato forest, Afromontane forest, carbon storage, carbon sequestration rate, climate change, carbon credit.*

I. INTRODUCTION

Forests are land use systems with high tree population and store large quantities of C (Lal 2005). Forest ecosystem store more than 80% of all terrestrial aboveground C and more than 70% of all soil C (Batjes 1996). According to Batjes (1996) the pedologic and biotic pools together are called the terrestrial C pools, and they are estimated at 2860 Pg or 2860 Gt (1Gt = 1Pg = 1 billion metric tons). Terrestrial C is the C stored in terrestrial ecosystems as living or dead plant biomass (aboveground and belowground) and in the soil along with usually negligible quantities as animal biomass. The main C pools in tropical forest ecosystem are the living biomass of tree and understory vegetation, dead mass of litter and woody debris, and soil organic matter. The vegetation of tropical forests is a large and globally significant storage of C because tropical forests contain more C per unit area than any other land cover (Hairiah et al. 2011). The forest resources of Ethiopia store 2.76 billion tons of C (about 10 billion Mg of CO_2) in the aboveground biomass (Yitebitu Moges et al. 2010). Forests can be both sources of atmospheric CO_2 when disturbed by natural or human causes, and sinks, when vegetation and soil C accumulate after disturbance, depending on land management thus potentially accelerating or mitigating climate change (Lal 2004).

The REDD$^+$ strategy, namely "reducing emissions from deforestation and forest degradation, and foster conservation, sustainable management of forests and enhancement of forest C stocks (through afforestation and regeneration) are keys to ensure net positive C addition that would then become a credit that could be sold in an international C market. However, the potential of C financing through REDD+ on forest C sequestration in tropical forests has not been systematically studied. The general allometric models developed by Pearson et al. (2005) and Chave et al. (2005) have been widely used, notably in the context of REDD+, and were recommended by the IPCC guidelines (IPCC 2006) for estimating C stocks in tropical forests. The general model developed by Chave et al. (2005) including tree height provided best biomass estimates specifically for moist tropical forests and reduce uncertainties as compared to other generic models (Ervan et al. 2013).

Afromontane forests are among the most species-rich ecosystems on earth (Schmitt et al. 2010). The study was conducted in Chato Afromontane forest ecosystem, one of the largest sacred forests in Ethiopia comprising of untouched natural forest and tree plantations. Although not studied so far, the wide range of tree plantations and high endemic plant species in Chato forest makes it the most powerful C sinks in the tropics. Therefore, the study was designed mainly to estimate C storage capacity and CO_2e

sink of the forest ecosystem so as to unveil the climate change mitigation and economic prospective of the forest.

II. MATERIALS AND METHODS

2.1. The study site

Chato forest is situated between 9.62898256 to 9.810748292N and 36.90419252 to 37.06710714E (Fig. 1) in the western parts of Ethiopia with an elevation ranging from 1700 to 2350 m asl. It is found at about 30 km north-west of Shambu, the capital city of Horo Guduru Wollega Zone, Oromia Region. The forest was demarcated as National Forest Priority Areas (NFPA) and has been known by the name Chato-Sangi-Dangab forest in the country (EFAP 1994). The forest is classified under moist evergreen Afromontane forest consisting high diversity of endemic tree species and a variety of wildlife. Chato forest covers about 14,290.97 hectares (ha) of land comprising of species rich natural forest (13670.06 ha) and various tree plantations including 17 to 29 years old acacia spp. (6.05 ha), 18 to 31 years *Cupressus lusitanica* (434.21 ha), 25 to 31years old *Juniperus procera* (2.97 ha), 14 to 31 years old *Gravellia robusta* (3.43 ha) and 14 to 31 years old eucalyptus spp. (174.25 ha) such as *Eucalyptus citrodora*, *Eucalyptus saligna*, *Eucalyptus comandulus*. The area is characterized by having unimodal rainfall distribution with mean annual rainfall of 1566 mm and mean annual temperature of 16.7 ^{0}C.

2.2. Forest stratification and sampling techniques

Compartments or strata established during forest inventory by Horo Guduru Forest and Wildlife Enterprise, mainly based on forest stand type was used for biomass assessment. Besides, part of the forest that was not addressed during inventory by the Enterprise was stratified during the study. The area of each forest stand was tracked by using ground positioning system (GPS). In the stratum or forest stand, nested sample plots of 20 m x 20 m, 2 m x 2 m and 1 m x 1 m were randomly laid to measure the biomass of woody plants, herbaceous/saplings and litter biomasses, respectively. A total of 105 sample plots were taken for C stock inventory. Sample plots in the same stand, namely eucalyptus, acacia, *Cupressus lusitanica*, *Juniperus procera*, *Gravellia robusta* and natural forest were weighed to give average biomass and C stock for each stand type.

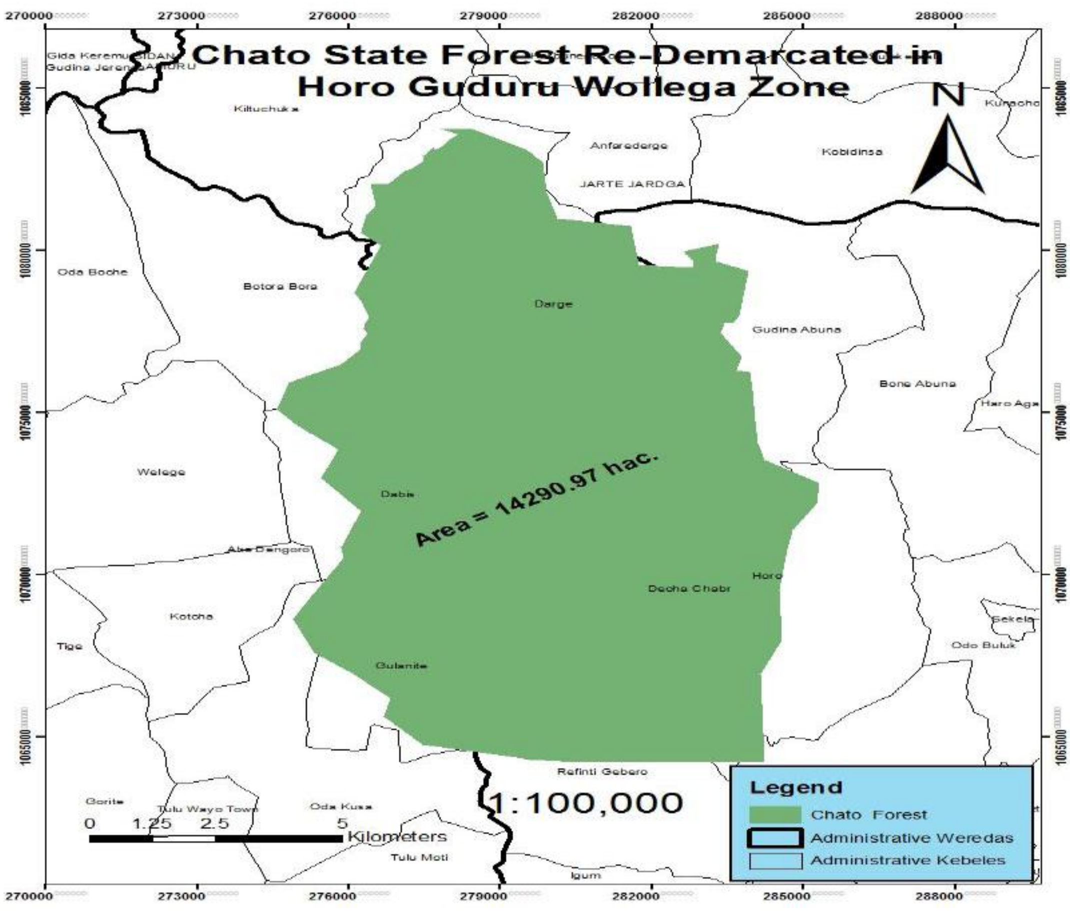

Fig. 1: Areal coverage and location map of Chato state forest

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2.3. Soil sampling and analysis

Carbon stock inventory for the soil was done for the upper 60 cm depth in the nested plot, by collecting samples from 0–30 and 30–60 cm layers at 20 locations. Following sample preparation, samples were analyzed based on the standard laboratory procedures. Bulk density was determined using core method (Blake and Hartge 1986) while SOC was determined using Walkley–Black oxidation method (Walkley and Black 1934).

2.4. Estimation of biomass in different pools

The major biomass components or pools assessed include aboveground live biomass, dead tree biomass, below ground biomass, and litter biomass.

2.4.1. Aboveground live biomass (AGLB)

In each 20 m x 20 m sampling plot, diameter at breast height (DBH) and tree height (H) were measured for every live tree using caliper and hypsometer, respectively. Then, the aboveground biomass of live trees with DBH ≥ 5 cm was estimated by using general allometric equation recommended by Chave et al. (2005) for moist tropical forest stands as indicated hereunder:

$$AGTB = 0.0509 * (\rho D^2 H) \qquad (1)$$

where *AGTB* is aboveground tree biomass (kg), ρ is wood specific gravity (g cm^{-3}), *D* is tree DBH (cm), and *H* is tree height (m). Besides, live grasses, shrubs, herbs, saplings, and some tree seedlings from natural regeneration with a DBH < 5 cm (Pearson *et al*., 2005) were harvested in each 2 m x 2 m subplot located in every corner and center of the main plot (400 m^2) in the nest. In 4 m^2 subplot, total fresh weight of harvested plant material was measured, from which 500 g sample size was taken to the laboratory, oven-dried at 85 ^{0}C and reweighed to estimate the dry matter of aboveground grasses, shrubs, herbs and saplings biomass (AGHSB). Finally, aboveground live biomass was the sum of aboveground tree biomass and aboveground grasses, shrubs, herbs, and saplings biomass.

2.4.2. Belowground biomass (BGB)

Belowground biomass was estimated from aboveground biomass on the basis of root to shoot ratio of (0.24:1) recommended by Cairns et al. (1997) for moist tropical forests (woody and non-woody).

2.4.3. Dead tree biomass (DTB)

The dead tree biomass was estimated for standing and downed dead trees following (CSEMF 2011) equations. Standing dead tree biomass (SDTB) was estimated by classifying the dead tree into three classes. The first class works for standing dead tree with small and large braches and twigs but without leaves. In this case, general allometric equation was used to estimate biomass and 2% was deducted due to absence of leaves. The second class works for standing dead tree with no twigs but only some large branches. In this case:

$$Volume\,biomass = \left(\frac{\pi * H}{12}\right)\left(D_b^2 + (D_b + D_t) + D_t^2\right) \qquad (2)$$

The third class works for standing dead tree with bole (trunk) only. In this case:

$$Volume\,biomass = \frac{(D_b^2 * D_t^2) + H}{8} \qquad (3)$$

where *H* is height of stem, D_b and D_t are diameter at base of the tree and top of the stump, respectively. Downed dead tree biomass (DDTB) was determined from volume estimate as:

$$Volume\,biomass = 0.25\pi\left(\frac{D_b + D_t}{2 * 100}\right)^2 * H \qquad (4)$$

where volume of dead wood (m^3), D_b is diameter of the base of the dead wood (cm), D_t is diameter of the tip of the dead wood (cm), H is length of the dead wood (m).

For standing dead trees of case 2 and 3 and downed dead trees, sample wood density was estimated by floating method (by cutting a disk of wood) and drying until a constant mass was obtained. Hence, wood density was estimated by dividing dry weight of the disk by volume of the disk. Subsequently, standing dead tree biomass of class

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2 and 3 and downed dead tree biomass was estimated by multiplying volume biomass by their wood densities. Biomass of standing dead tree under each case was summed up to give total SDTB. Finally, SDTB and DDTB were summed to provide DTB.

2.4.4. Litter biomass (LB)

The dry matter of litter and finer plant debris was collected from 1 m x 1 m plot in every four corners and center of the main 400 m^2 plot in the nest. In the 1 m^2 plot, litter was collected and total fresh weight was recorded, from which 250 g sample size was taken to the laboratory, oven-dried at 85 ^{0}C and reweighed to estimate the dry matter.

2.5. Calculation of carbon stock from biomass

The amount of C stored in each pool (kg) was determined by multiplying the biomass of each pool (kg) to 0.50 (Payton and Waever 2011) as follows:

$$C_X = Biomass * 0.5 \quad (5)$$

2.6. Calculation of carbon storage capacity

Then, C storage capacity (Mg ha^{-1}) was calculated by dividing the C_x stored in each pool and each subplot (kg) by area of the subplot (m^2) and multiplying with 10 as follows:

$$C\ storage capacity = \left(\frac{Cx}{A}\right) * 10 \quad (6)$$

where C storage capacity was estimated for each types of pools (i.e. AGB, BGB, DTB, and LB) expressed as Mg ha^{-1} and 10 is a conversion factor from kg m^{-2} to Mg ha^{-1}.

2.7. Estimation of soil organic carbon (SOC)

The SOC (Mg ha^{-1}) to specific soil depth was estimated as:

$$SOC = OC * \rho b * d * CFU \quad (7)$$

where *OC* is mg g^{-1} C concentration, *d* is soil thickness or depth i.e. 0–30 and 30–60 cm, ρ_b is bulk density of the soil (g cm^{-3}) and *CFU* is correction factor for units (= 10^{-1}).

2.8. Quantifying total carbon stock (TCS)

The total C stock in the nested plot expressed in (Mg ha^{-1}) was calculated by adding C stored in all pools in each subplot in the nest according to the equation:

$$C_{plot} = C_{AGLB} + C_{BGB} + C_{DTB} + C_{LB} + SOC \quad (8)$$

where C_{AGLB}, C_{BGB}, C_{DTB}, C_{LB}, and *SOC* were C stored in the aboveground live biomass, belowground biomass, dead tree biomass, litter biomass, and in the soil in the subplots expressed in (Mg ha^{-1}), respectively. The amount of C stored in each types of forest stand (Mg) was calculated as follows:

$$C_{st} = \left(\frac{\sum C_{plot}}{n_{plot}}\right) * A_{st} \quad (9)$$

where C_{plot} is the total C stored in each plots expressed in (Mg ha^{-1}), n_{plot} is the number of sample plots in the stand, A_{st} is area of each stand (ha). The total C stock in the whole forest was calculated as follows:

$$C_T = \sum C_{st} \quad (10)$$

where C_T is total C stock (Mg) and C_{st} is the total C stock of each forest stand (Mg).

2.9. Estimation of equivalent CO_2 sink

Finally, as 1 Mg of soil C = 3.67 Mg of CO_2 sequestered (Craig *et al*., 2010), the equivalent CO_2 sink (Mg) in Chato forest was estimated based on the total C stock as follows:

$$CO_2e = 3.67 * C_T \quad (11)$$

Values in Gg can be obtained by dividing Mg of OC or CO_2 by 1000.

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2.10. Statistical data analysis

Descriptive statistics was used to summarize mean and coefficient of variation of measured parameters. Generalized biomass models developed for moist tropical forests were used to determine carbon stock of forests. Mean separation was carried out using least significant difference (LSD) at $p< 0.05$.

III. RESULTS AND DISCUSSION

3.1. Impact of stand type and biomass component on biomass accumulation

Biomass accumulation in forest ecosystems usually influenced by kind of forest, type of pool, tree size class and density, species composition, forest age, and level of protection, all of which determine the C storage level of the forest. The study result shows that Chato natural forest had accumulated large volume of biomass than plantation forest for similar pools (Table 1). Total biomass accumulation, the sum of biomass stored in all components, was highest for natural forest followed by plantations including eucalyptus species, *Cupressus lusitanica*, *Juniperus procera*, *Gravellia robusta*, and lowest for acacia species. Larger biomass in natural forest might be attributed to maturity, species diversity and good understory cover.

The study result shows that the average biomass stored (Mg ha^{-1}) in different biomass pools decreased in order AGB > BGB > LB > DTB for all types of forest stands. The quantity of biomass accumulated in the aboveground biomass pool was significantly different from other pools at ($p< 0.05$) indicating more biomass was accumulated in the aboveground pool. The mean biomass accumulated in Chato forest by biomass components ranged from 2.73 Mg ha^{-1} in the dead tree to 315.90 Mg ha^{-1} in the aboveground biomass pools. Canopy cover, basal area, and height of trees might be attributed for the larger proportion of biomass in the aboveground biomass pool. The average value of the aboveground biomass for natural forest in the present study (603.72 Mg ha^{-1}) was higher than the findings of Brown and Lugo (1982) and Abel Girma et al. (2014) who reported a range of 225 to 446 Mg ha^{-1} for the tropical rain forests in Malaysia and a mean value of 475.51 Mg ha^{-1} for woody plants of Mount Zequalla Monastery in Ethiopia, respectively. However, the present result is almost similar with the aboveground biomass values of 607.7 Mg ha^{-1} reported for tropical wet evergreen forest of western India (Rai 1981) and less than 994.16 Mg ha^{-1} reported for forest in the lowland area of Simien mountains national park of Ethiopia (Tibebu Yelemfrhat et al. 2014). The average aboveground biomass for plantation forest in the present study (258.34 Mg ha^{-1}) was less than the aboveground biomass of plantation forest in the humid tropics in northeast India (406.4 Mg ha^{-1}) (Ratul et al. 2009) but greater than 223.6 Mg ha^{-1} reported by Wondrade et al. (2015). Nearly 78.99% of total biomass in the natural forest was allocated in the aboveground biomass (Table 2) while the remaining pools accumulated only 21.01% biomass. In all forest stands, the smallest biomass was recorded in the dead tree/wood compared with other pools. Low tree mortality and decomposition of deed woods might be the causes for low dead tree biomass. The aboveground shrubs and saplings biomass was highly variable with stand type than other pools as depicted by larger coefficient of variation (76.73%) (Table 1). This could be due to differences in suitability of various forest stands for the understory growth and it was more vigorous in the natural forest than plantations.

Table.1: Average biomass accumulation in the different forest stands and biomass components

Forest category	Biomass storage (Mg ha^{-1}) in different components					Total
	AGTB	AGHSB	BGB	DTB	LB	
Eucalyptus spp.	396.34	13.80	98.43	3.18	6.50	518.25
Acacia spp.	90.35	9.13	23.87	0.67	2.80	126.82
Cupressus lusitanica	353.83	6.45	86.47	3.53	4.20	454.48
Juniperus procera	233.69	8.05	58.02	3.14	3.50	306.40
Gravellia robusta	175.73	4.33	43.21	0.31	2.30	225.88
Natural forest	574.54	29.18	144.89	5.52	10.20	764.33
Mean	304.08^{b}	11.82^{a}	75.82^{a}	2.73^{a}	4.92^{a}	
CV (%)	57.20	76.73	57.42	71.50	60.61	

AGTB: aboveground tree biomass; AGHSB: aboveground grasses, herbaceous, shrubs, and saplings biomass; BGB: belowground biomass; DTB: dead tree biomass; LB: litter biomass; and CV: coefficient of variation. AGB = AGTB + AGHSB. Means within rows followed by different letters are significantly different at ($p< 0.05$).

Table.2: Percent biomass allocation in different pools for various forest stands

Type of forest	Biomass allocation (%)			
	AGB	BGB	DTB	LB
Eucalyptus spp.	79.14	18.99	0.61	1.25
Acacia spp.	78.44	18.82	0.53	2.21
Cupressus lustanica	79.27	19.03	0.78	0.92
Juniperus procera	78.90	18.94	1.02	1.14
Gravellia robusta	79.71	19.13	0.14	1.02
Natural forest	78.99	18.96	0.72	1.33

Previous research indicated that matured forests do not add up significant quantity of biomass because there is no net addition to the aboveground biomass density (Ratul et al. 2009). Instead, they are important for regeneration and sustaining a large volume of an already accumulated biomass and biodiversity. Newly established plantations are; however, add significant quantities of biomass to the ecosystem. The contribution of younger forests to the net addition of biomass varied with the rate of growth suggesting fast growing trees have an increasing biomass storage rate than slow growing ones until the time of maturity.

3.2. Carbon storage capacity of different forest stands and pools

The total C storage capacity of different stands decreased in the following order: natural forest > eucalyptus species > *Cupressus lusitanica* > *Juniperus procera* > *Gravellia robusta* > acacia species (Table 3). The mean C storage capacity of the natural forest in the entire pools was 453.21 Mg ha^{-1} whereas that of plantations (viz. eucalyptus species, *Cupressus lusitanica*, *Juniperus procera*, *Gravellia robusta*, *and* acacia species) was 208.08 Mg ha^{-1}. Species richness, full ceiling canopy and several layers of understory might have contributed to the larger C storage potential of the natural forest. The average C storage capacity of Chato natural forest was greater than that of tropical rain forest of Malaysia (223 Mg ha^{-1}), Indonesian forests (161 Mg ha^{-1}) and Philippines forest (258 Mg ha^{-1}) but smaller than the intact natural forests in south-eastern Australia (640 Mg ha^{-1}) reported by Brown and Lugo (1982), Murdiyarso and Wasrin (1995), Lasco et al. (2006) and Brendan et al. (2008), respectively. Combining C stored in the natural forest and plantations, the mean C storage capacity of Chato forest in the entire pools was 248.93 Mg ha^{-1}.

Table.3: Average C storage in the different pools by major forest stands

Forest stand	C storage capacity (Mg ha^{-1}) in different pools					Total
	AGC	BGC	DTC	LC	SOC	
Eucalyptus spp.	205.07	49.22	1.59	3.25	41.70	300.83
Acacia spp.	49.74	11.94	0.33	1.40	43.72	107.12
Cupressus lustanica	180.14	43.23	1.77	2.10	53.16	280.40
Juniperus procera	120.87	29.01	1.57	1.75	62.01	215.21
Gravellia robusta	90.03	21.61	0.16	1.15	23.89	136.83
Natural forest	301.86	72.45	2.76	5.10	71.04	453.21
Mean	157.95^{c}	37.91^{ab}	1.36^{a}	2.46^{a}	49.25^{b}	
CV (%)	57.42	57.42	71.50	60.61	33.78	

Means within rows followed by different letters are significantly different at ($p< 0.05$). AGC: aboveground carbon; BGC: belowground carbon; DTC: dead tree carbon; LC: litter carbon; and SOC: soil organic carbon.

The C storage capacity varies with type of pool. The AGC pool and SOC were significantly different from other pools and from each other at ($p< 0.05$). The DTC and LC were also significantly different from AGC and SOC but not significantly different from each other at ($p< 0.05$). The study shows that the mean C stock of the major pools in each forest stands decreased as AGC > SOC > BGC > LC > DTC, implying more C allocation in the aboveground pool

(Fig. 2). Nearly 63.45% of C was stored in the aboveground pool followed by 19.79, 15.23, 0.99 and 0.55% in the soil, belowground, litter, and dead tree, respectively. This was in line with Zerihun Getu et al. (2012) report that tropical forests in their natural condition contain more aboveground C per unit area than any other land cover type. The average C stored in the aboveground pool for natural forest was 301.86 Mg ha^{-1} while that of plantation forest was 129.17 Mg ha^{-1}. Combining the C sequestered in the natural forest and plantations, the mean aboveground C storage capacity of the forest was 157.95 Mg ha^{-1}. The average aboveground C for natural forest in the present study (301.86 Mg ha^{-1}) was larger than the average C in the aboveground biomass for tropical forests in Malaysia (149 Mg ha^{-1}) but smaller than estimates in the Phillipines (406 Mg ha^{-1}) reported by Tara (2012) and Lasco et al. (2006), respectively. The study result indicated that average aboveground C in the tree plantations was better in eucalyptus species (205.07 Mg ha^{-1}) and *Cupressus lusitanica* (180.14 Mg ha^{-1}) as they are relatively older than other tree plantations. The mean belowground C for the natural forest (72.45 Mg ha^{-1}) was much higher than that tropical forest in Malaysia (27 Mg ha^{-1}) (Tara 2012). The contributions of dead tree C and litter C pools to the total C pool were minor which might be due to decomposition of dead wood over time leading to loss of C.

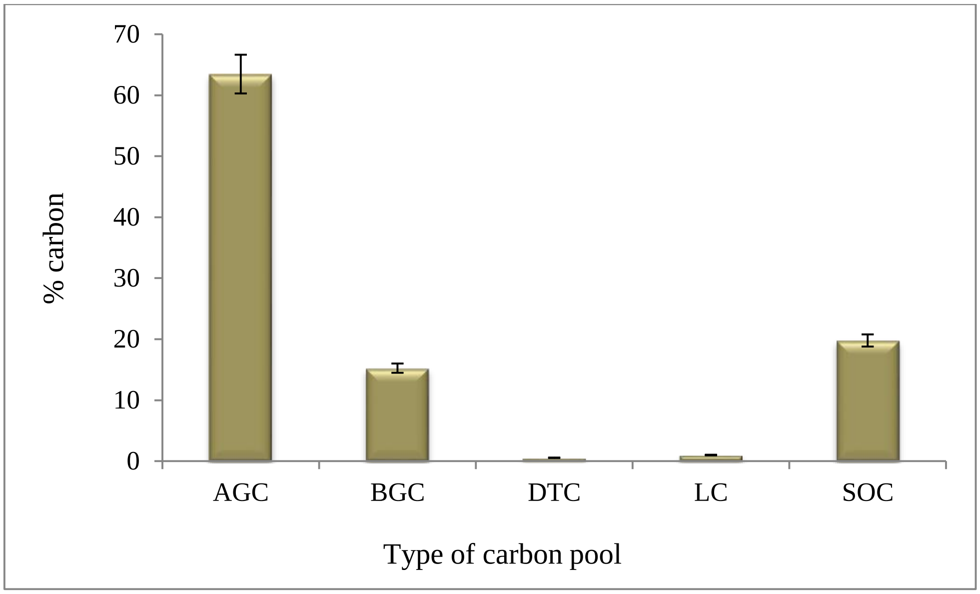

Fig. 2: Carbon partitioning/mean proportion of C stock in different pools in Chato forest

The mean SOC storage potential to a depth of 60 cm in Chato forest was 49.25 Mg ha^{-1}, where natural forest and plantations stored averagely 71.04 Mg ha^{-1} and 44.90 Mg ha^{-1}, respectively. The average SOC for natural forest in the present study was a little higher than SOC stock range of 58.3 to 63.9 Mg ha^{-1} reported by Solomon et al. (2002) for humid tropical forest in southeastern Ethiopia and that of plantations is at par with 44.2 Mg ha^{-1} reported by Thomas et al. (2015). Mulugeta Lemenih et al. (2005) also found SOC storage of 23.4 Mg ha^{-1} for *Cupressus lusitanica* plantation which is lower than the result of the present study (53.16 Mg ha^{-1}). The amount of C stored in the soil was affected by aboveground biomass, species richness, age and density of forest and the understory cover. In systems with high plant diversity like natural forest, it is likely that they would have litters with different degrees of chemical resistance; creating the possibility of longer residence of C through slower decomposition of litters and build up of soil C. As C is generally a more variable parameter, coefficient of variability (CV) was high for most C pools investigated within different forest stands (Table 3). Relatively, C stock variation within stand type was highest in dead tree carbon pool (71.50%) and lowest in SOC pool (33.38%). This implies C in the vegetation is more variable than C in the soil.

3.3. Net carbon sequestration rate

A study by Popo-ola et al. (2012) indicated that planting new forests, rehabilitating degraded forests and enriching existing forests contribute to mitigating climate change as these actions increase the rate and quantity of C sequestration in biomass. Plantation forest established in the study site some 31 years back had added nearly 175.93 Gg C to the forest ecosystem. Our result shows that the average C sequestration rate for the plantations of varying age was 8.65 Mg ha^{-1} yr^{-1}; the quantity higher than the average value

of 3.98 Mg ha^{-1} yr^{-1} for mixed plantation forest in China reported by Yuanqi et al. (2015). Previous research indicated that plantation forests are a cost-effective means of sequestering C (Adams et al. 1999). Among plantations, eucalyptus species and *Cupressus lusitanica* were relatively matured and thus, stored more C than young tree plantations (Table 3). Young forest holds less C, but it is sequestering additional C over time. An old forest may not be capturing significant quantity of net new C but can continue to hold large volumes of C in the form of biomass over long periods of time. In line with this Lewis et al. (2009) indicated that old natural forests may not be C neutral but continue to be C sinks and observed a slow increasing tree C storage rate of 0.49 Mg ha^{-1} yr^{-1} in African tropical old growth forests.

3.4. Impact on climate change mitigation and economic potential

Forests serve as C sinks; absorb C from the atmosphere and store in the wood, soil and other organic materials. For the entire area of study site (14290.97 ha), a total of 6371.30 Gg C was stored in the forest ecosystem (Table 4). Deforestation of each 1 ha of natural forest and plantations would cause the loss of about 453.21 and 208.08 Mg C, respectively. Deforestation of the whole forest would cause emission of 23382.65 Gg CO_2 to the atmosphere. However, owing to protection of existing forests and expansion of plantations in the study area, there is rather a net addition of C to the forest ecosystem. Perez et al. (1997) suggested that the additional C sequestered from afforestation and reforestation could offset even the C release from deforestation.

Table.4: Total C stock and equivalent carbon-dioxide sink across different forest stands

Forest category	Total C stock (Gg)	Equivalent CO_2 sink (Gg)
Eucalyptus spp.	52.42	192.38
Acacia spp.	0.65	2.38
Cupressus lustanica	121.75	446.83
Juniperus procera	0.64	2.35
Gravellia robusta	0.47	1.72
Natural forest	6195.37	22737.00

*1 Gg = 1000 tons

As net gain is the main concern, the jungle forests of Amazon cannot be qualified for REDD+ if there is no positive addition of C to the system. In our study, we recognized that the undisturbed Chato forest fulfills the key REDD+ strategic areas and would be eligible for the international C market. By continuing the current afforestation and forest management program, the forest will be a potential emission reduction center. Tree seedling plantations on bare lands around the forest need to be strengthened to add more C to the system. Community should be empowered to own the forest and protect from potential dangers. Local government authorities need to be transparent and strong enough to protect the forest from potential destruction by private firms and individuals who involve in timber production, if any.

IV. CONCLUSION

Forest type and maturity stage affects biomass accumulation in forests. Undisturbed and matured natural forest stored more biomass than plantations. Carbon allocation was by far larger for the aboveground pool than any other pools. Intactness and species diversity of Chato moist Afromontane forest makes it one of the largest C reservoirs in the tropics. Younger and fast growing plantations have better C sequestration rate than the old forest and ensures net positive C additions to the ecosystem. Large volume of annually trapped C by the vast channels of Chato forest makes it the most significant regulator of global climate change. Sustaining the afforestation and forest management programs will possibly ensure the viability of the forest for REDD+ projects. Lastly, more research is required to explore the untapped potential of the forest and give due attention to develop C models specific to the sacred Afromontane forests.

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